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REPORT NUMBER 1061

THE EFFECTS OF COLOR-CODING IN GEOSIT DISPLAYS

I. Color as a Redundant Code

by

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and
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Naval Medical Research and Development Command
Research Work Unit M0100.001-1022

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SUMMARY PAGE

PROBLEM

To determine the effects on search performance of color-coding symbols on geographical situation (GEOSIT) displays.

FINDINGS

The application of a fully redundant color code to the threat dimension resulted in highly significant reductions in search and counting times when the target contact was one of the three threat levels. Color had no effect on response times for the platform dimension that was not color-coded. Response times were significantly faster for the Surface symbols than for either the Submerged or Airborne symbols.

APPLICATION

This study proves that one possible application of a color code to GEOSIT displays of submarine sonar and fire control systems can significantly improve performance on a search task, without interfering with non-color-coded information.

ADMINISTRATIVE INFORMATION

This research was conducted as part of the Naval Medical Research and Development Command Work Unit M0100.001-1022 -- "Enhanced performance with visual sonar displays". This report was submitted for review on 5 August 1985, approved for publication on 13 September 1985 and designated as NSMRL Report No. 1061.

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ABSTRACT

The effect of color-coding symbols in geographical situation (GEOSIT) displays on response time was studied using 12 observers. Three levels of the threat dimension (Friendly, Unknown, and Hostile) were redundantly coded by both color and shape, while the three levels of the platform dimension (Submerged, Surface, and Airborne) were coded only by shape. Compared to the standard monochrome coding scheme, response time on the color-coded threat dimension was enhanced by over 100%. Performance on the non-color-coded platform dimension was unaffected by color-coding of the threat dimension. Several other significant effects were also found. This study demonstrates that the use of color in GEOSIT displays can dramatically improve performance without any decrement in performance on non-color-coded information.

In recent years there has been an increasing amount of interest in, and research on, the application of color to cathode-ray tube (CRT) displays. Christ (1975) reviewed a large body of this literature. In general, he concluded that color-coding is superior to other coding schemes in search type tasks where observers must locate and/or count instances of a particular item when these items are displayed among many others (Carter, 1982; Cook, 1974; Hoops, 1984). As pointed out by Christ, this superiority is found whether color-coding is redundant or not.

The addition of color to a display is not always advantageous, however and has, in fact, been reported to decrease performance in some situtations (Neri & Zannelli, 1984). For example, color has been reported to interfere with non-color-coded dimensions when it is irrelevant (Eriksen, 1954; Smith & Thomas, 1964), and sometimes even when it is relevant (Green & Anderson, 1956). More recently, Luder and Barber (1984) have suggested that where two kinds of information are separately encoded, a redundantly color-coded dimension may interfere with a non-color-coded dimension, due to an observer's inability to inhibit the color attribute even when it is irrelevant.

These issues are especially pertinent to the possible color-coding of symbols on geographical situation (GEOSIT) displays. These displays are used in submarines to provide pictorial summaries of the types of contacts in the vicinity of the vessel. Operators using a GEOSIT display often perform search and counting tasks that are similar to classical search and counting tasks. This suggests that color-coding of the symbols might be one application of color in sonar and fire-control displays that would most likely enhance performance over that obtained with monochrome displays.

In the present study, symbols were used to provide information about contacts on three levels of two dimensions: (1) threat category (Friendly, Unknown, and Hostile) and (2) type of platform (Submerged, Surface, and Airborne). The possible number of colors that can be employed in color-coding these symbols is three or nine. depending on whether one or both dimensions are color-coded. Although recent studies in our laboratory have shown that more than ten colors are easily discriminable and accurately identifiable (Jacobsen & Neri, 1985; Jacobsen, 1985; Luria, Neri & Jacobsen, in press) color-coding of all nine symbols may introduce too much visual clutter in the GEOSIT displays. In this study we, therefore, decided to

color-code only the threat dimension as it is arguably the more important dimension to be identified quickly and accurately by the operator. Hence only three colors were employed in the color-coding scheme.

Another question that arises is whether to simply add color to the coding scheme (redundant color-coding) or use color alone to code threat level (non-redundant color-coding). There has been concern that the introduction of non-redundant color-coding would result in serious operability problems should one or two of the three electron guns in the CRT fail, resulting, respectively, in a severely altered chromatic, or completely monochromatic display. It would then become difficult, if not impossible, to distinguish between symbols that were previously only color-coded, without the capability to instantly change the display to a strictly shape-coded or alphanumeric-coded one. These concerns have led us to initially examine color as a fully redundant code, thereby retaining all information currently provided to the operator, and simply adding color information as another tool for the operator to use in interpreting data.

A decision also must be made as to the three colors to use. Neri & Zannelli (1984) have argued for the "traffic light" scheme of cyan (blue-green), yellow, and red for the color-coding of the threat dimension as these seem to have a natural associative bias to the threat levels of Friendly, Unknown, and Hostile. Other colors could then be used to encode other pieces of information in these displays, such as own ship, land masses, etc.

In applying this redundant color-coding scheme of cyan, yellow, and red to the threat levels, we addressed three basic issues. First, what, if any, enhancement in performance on a search and counting task is obtained when threat levels are coded by color? As mentioned above, our prediction, based on the literature, is for some enhancement, but the amount is not clear.

A second, equally important, but less obvious question is, what, if any, is the effect on the non-color-coded dimension of platform type? Since color has been shown to sometimes have an interfering effect when irrelevant (as is the case here, with color being irrelevant to the platform dimension), will color-coding threat level actually cause a decrease in performance when searching for contacts of a particular platform type?

A final question concerns the possible interaction between the density of the target contacts and the effect of color-coding. Cahill & Carter (1976) have suggested that color readily facilitates a perceptual grouping or "Gestalt" of items which stands out from the background. This perceptual effect may depend on the target contact density, however. The present study made use of a search and counting task in which the display was divided into four quadrants. Observers were asked to locate the quadrant that contained the most of a specific type of contact category. The question of a density by color-coding interaction was studied by varying the difference in number of target contacts among the quadrants. In high target density quadrants, where the target quadrant had at least four more target contacts than any other quadrant, it was believed that shape alone might be salient enough to form a Gestalt. In low target density quadrants, however, where the difference in number of target contacts was only one or two, shape alone might not be sufficient to form a Gestalt. In these situations color might have a stronger effect on performance as it would permit the formation of a Gestalt. Hence, it was thought that color-coding might interact differently with the high versus low target density quadrants.

The present study was designed to answer all of these questions by comparing a redundant application of color to GEOSIT displays with the existing monochrome-coding scheme, and analyzing its effects on both the color- and non-color-coded dimensions, for high and low target density quadrants.

METHOD

Subjects

Twelve Navy Seamen and Petty Officers at the Naval Submarine Base, New London, served as voluntary observers. All had normal color vision as determined by the Hardy-Rand-Rittler pseudo-isochromatic plates. Those who normally wore corrective lenses did so during the experiment.

Apparatus

Simulated GEOSIT displays were presented on an Advanced Electronics Design Model 512 Color Graphics and Imaging Terminal, driven by a Digital PDP 11/34 Laboratory Computer. Observers were seated approximately 50 cm from the terminal

screen placed at eye level. Responses were recorded via a pad with four microswitches mounted in a square pattern and wired to the computer. A fluorescent light, situated above and behind the observer, cast 2.7 lux of illumination on the CRT screen. This is the highest amount of light typically illuminating sonar equipment under operational conditions (Kinney, Luria, Neri, Kindness, & Schlichting, 1981). A Kodak Carousel 800 projector was used to present slides on a white cardboard screen during an initial training phase.

Stimuli

There were 16 simulated GEOSIT displays. All had the same fictitious land and sea map, with the land outlined in green. Each display was divided into four quadrants by a white crosshair with contacts appearing in various locations. The 16 displays differed in the distribution of the contact symbols in the quadrants.

Each contact was coded both as a given platform type (Surface, Airborne, Submerged) and a given threat level (Friendly, Hostile, Unknown). Each of the nine types of contacts (three platforms X three threat levels) was presented in four different locations. This resulted in a total of 36 contacts in each display. Observers were instructed to search for a type of contact that was defined on only one dimension. Thus they were never asked to search for "Friendly Airborne" contacts, for example, but might be asked to search for "Friendly" contacts or for "Airborne" contacts.

The contacts were presented in random locations except for these constraints: there were nine contacts in each quadrant, they could not overlap each other or the crosshairs, and, of course, only the Airborne contacts could appear over land. In each display the quadrant that contained a plurality of a given type of target category was designated as the "target" quadrant, for which the observer was instructed to search. The displays had both low and high target density quadrants. A low target density quadrant was one in which there were only one or two more target contacts than any other quadrant. In a high target density quadrant, the difference was at least four. Typically, low target density quadrants contained four or five target contacts while high target density quadrants contained eight or nine target contacts. Each screen was used in more than one condition. For example, the same display screen might be used for a low target density Airborne display with quadrant one as the target quadrant and a high target density Submerged display with quadrant

four as the target quadrant.

Procedure

The testing was preceded by a training session in which the observers learned the symbology employed in the experiment. They were first shown a color slide of the coding scheme and given an explanation of it. The color green was used for all symbols in the monochrome scheme because it is different from any of the colors used in the color-code and because green is the color used in most monochrome CRTs currently on submarines. During this training, observers were also presented with four slides of each of the nine symbols utilizing the two codes of color and monochrome, for a total of 72. After viewing the coding scheme slide for as long as they desired, observers were then shown the monochrome set of 36 slides in a random order, asked to name the contact displayed and told if they were correct. Following this, they were shown the coding scheme slide again and then the 36 color-coded slides were presented with the same instructions. Virtually all observers responded correctly to all of the slides, with an occasional error occurring toward the beginning of training. The time taken by observers to respond decreased as they learned the code. By the end of the training, all of the observers could easily name the type of contact with either code.

In the experiment, 6 of the 12 observers started with the color-coded displays, 6 with the monochrome. The observer was told what target category to look for in a given set of trials (e.g. "Airborne", or "Hostile"). The sea and land masses of the display were then drawn by the computer, and, after a warning signal, the 36 contacts appeared simultaneously. The observer looked for the quadrant which contained the most target contacts and pressed the corresponding switch on the response panel as quickly as he could without sacrificing accuracy. The computer recorded the reaction time of the response and its correctness.

The order of presentation of the six target categories (three threat levels and three platform types) was counterbalanced such that each of the six observers that started with the monochrome condition, for example, started with a different category. Each of the six categories occupied each presentation position across the six observers. The target category presentation order was the same when these observers viewed the color-coded displays. The same procedure was used for those six observers viewing

the color-coded displays first. There were eight sequential trials for each of the six target categories, resulting in a total of 48 trials in each of the color and monochrome conditions. The two target densities (low or high) were randomized within the eight trials for a target category block, with four low target densities, and four high target densities appearing in each block. In the second code presentation condition (monochrome vs. color), this random order was reversed. The four presentations of each target density allowed for the counterbalancing of "target quadrants" across the four possible quadrant locations. This procedure resulted in a total of 96 trials per observer. The entire session, including training, took approximately one hour.

RESULTS

In order to expose any unwanted effect of target quadrant, mean response times were initially analyzed via a four-way (Code X Target Density X Target Category X Quadrant) repeated measures ANOVA. Trials on which observers had made errors were omitted from this analysis and these missing data were replaced with the means for that particular cell generated by all other observers. There were 37 errors out of a total of 1152 responses for an overall error rate of 3.2%. The ANOVA revealed no significant effect of quadrant and hence this factor was collapsed in all subsequent analyses.

There was a significant interaction between Code and Target Category according to a three-way (Code X Target Density X Target Category) repeated measures ANOVA ($F(5,55)=13.53$; $p<.01$). This interaction is depicted in Figure 1.

Simple main effects tests revealed that the three threat target categories were responded to significantly faster when they were color-coded than when they were not ($F(1,66)=25.31$, 32.53, and 33.13, respectively; $p<.01$). The three platform types, that were not color-coded in either condition, showed no significant difference in response times between the two coding conditions.

These simple effects tests also revealed significant differences among the response times to the six target categories under the color and monochrome conditions considered separately ($F(5,60)=27.12$ and 3.67, respectively; $p<.01$). Newman-Keuls means tests revealed that, under the color-coding condition, the three color-coded threat categories yielded significantly faster response times than

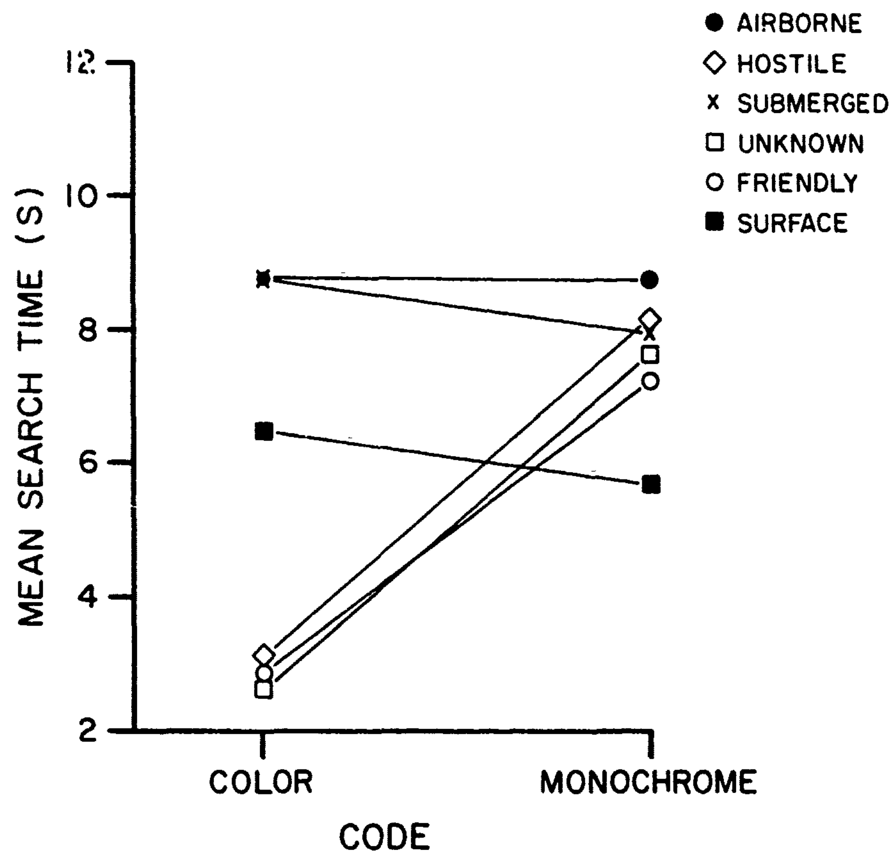

Figure 1. Mean search times for the six target categories using both codes, color and monochrome. The threat dimension was redundantly color-coded with shape in the color code condition, while the platform dimension was only shape-coded.

the three platform categories. In addition, of the platform categories, the Surface category was responded to significantly faster than either the Airborne or Submerged categories. Under the monochrome-coding condition it was found that only the Surface category was responded to significantly faster than all of the other target categories.

Another way of looking at the Code X Target Category interaction, shown in Figure 1, is to collapse the six target categories into the two types of coding dimensions: threat and platform. This was done in order to more clearly show the effect of redundant color-coding versus non-redundant shape-coding. (It should be remembered that with the color-coding condition, the threat dimension was redundantly color-coded with shape while the platform dimension was not). Figure 2 depicts the results of pooling the categories into the two dimensions. A three-way (Code X Target Density X Dimension) repeated measures ANOVA revealed a significant interaction between Code and Dimension ($\underline{F}(1,11)=21.12$; $\underline{p}<.01$). Simple effects tests revealed that the threat dimension was responded to significantly faster when it was color-coded, than when it was not ($\underline{F}(1,22)=40.74$; $\underline{p}<.01$). On the other hand, the platform dimension did not differ significantly between the monochrome and color-coding conditions. The mean response times underlying this interaction are shown in Table 1. The only significant comparison was that under the color-coding condition, the threat dimension resulted in significantly faster response times than the platform dimension ($\underline{F}(1,22)=56.37$; $\underline{p}<.01$).

Table 1. Mean response times, in seconds, for the platform and threat dimenions obtained under the color and monochrome conditions.

	Color	Monochrome
Platform	7.97	7.43
Threat	2.86	7.66

The three-way Anova also revealed a significant interaction between Target Density and Dimension ($\underline{F}(1,11)=13.29$; $\underline{p}<.01$). This interaction was not analyzed further since the Target Density X Target Category analysis more precisely shows the cause of this interaction.

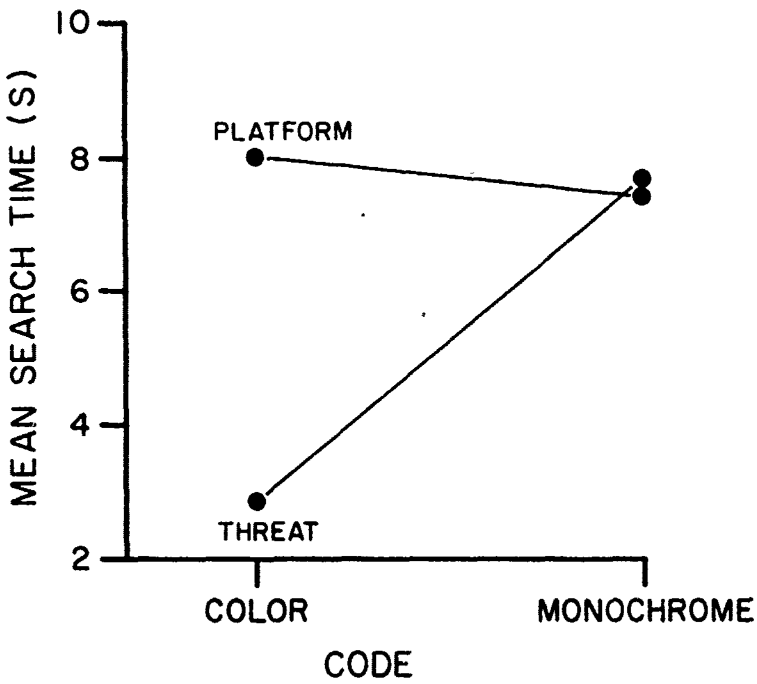

Figure 2. Mean search times for the threat and platform dimensions, collapsed across levels, using either color or monochrome coding. See Figure 1 for further details.

This interaction between Target Density and Target Category ($F(5,55)=6.25$; $p<.01$) collapsed across the two coding schemes is shown in Figure 3. Simple effects tests revealed that all six target categories resulted in significantly faster response times under the high target density condition than under the low target density condition. All of these differences were significant at the $p<.01$ level except for the Friendly category which was significant at the $p<.025$ level. The simple effects tests also revealed that there were significant differences among the six target categories under both the low and high target density conditions ($F(5,110)=26.95$ and 8.94, respectively; $p<.01$). The Surface, Hostile, Friendly, and Unknown categories were all responded to significantly faster than the Airborne and Submerged categories under both high and low target density conditions, according to the Newman-Keuls test. The Airborne and Submerged categories, that were responded to the slowest under the high target density condition, became even more difficult, relative to the other target categories, under the low target density condition.

DISCUSSION

Color vs. Monochrome

In general, the effects of color-coding were dramatic. Response times for items of the redundantly color-coded threat dimension were reduced by over 100%, with an average time of 7.66 s with the monochrome code versus 2.86 s with color-coding. This finding is consistent with much other research on color-coding of information in searching and counting tasks, where color has been found to be the most efficient type of coding scheme. The notion that color might improve performance more with low target density quadrants than with high target density quadrants was not substantiated by the data as no interaction between Code and Target Density was found.

Effects of Color-Coding on the Non-Color-Coded Dimension

Color-coding of the threat dimension had no significant effect on the non-color-coded platform dimension. It had been anticipated, based on previous research, that color-coding only one dimension might interfere with the other dimension. This interference effect was not found in the present study as seen by the absence of any significant difference in response times for the non-color-coded platform categories between the color-coded and monochrome conditions. Luder and Barber (1984) have suggested that

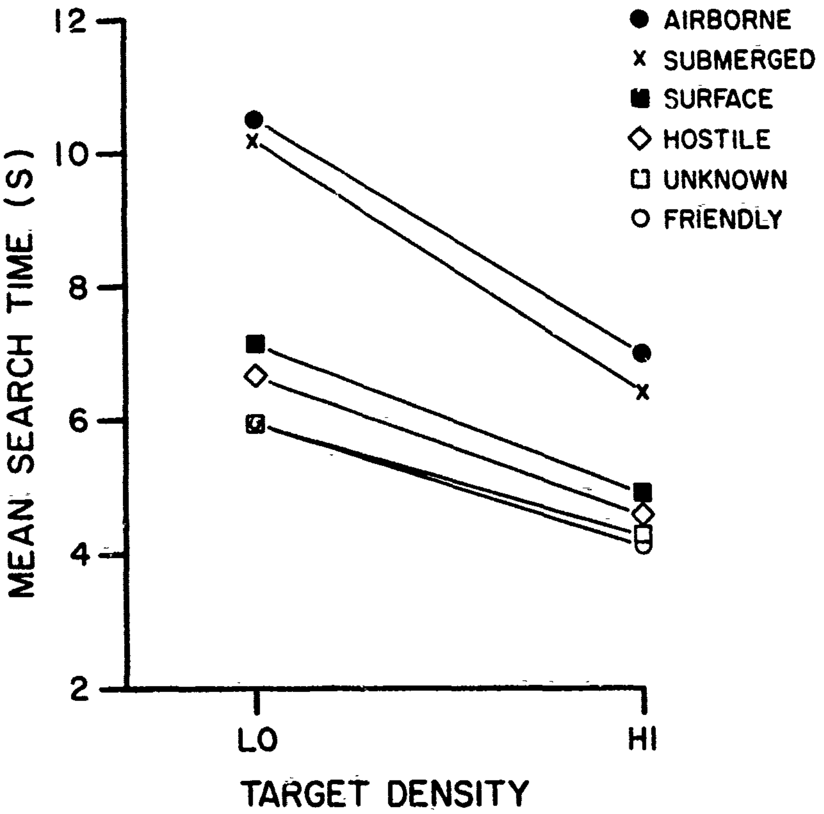

Figure 3. Mean search times for the six target categories under the low and high target density conditions. Note that the data include both color and monochrome conditions, combined.

color as a redundant code may interfere with a non-color-coded dimension because color has a strong psychological precedence over other dimensions such as shape. The present results demonstrate, however, that performance on a non-color-coded dimension is not always adversely affected by a second color-coded dimension. In the present study, observers were required to count the number of times a contact appeared in each of the four quadrants. When counting one of the platform categories, Airborne for example, it is conceivable that observers might first count all of the Hostile Airborne in a quadrant, then all of the Unknown Airborne and finally all of the Friendly Airborne. Color-coding should not interfere with the non-color-coded dimension with this type of strategy, even if the color-code is more prominent than the other code. Consequently, although color-coding may interfere with performance on non-color-coded dimensions in some tasks, the effect depends on the type of task.

Effect of Target Density

Response times were significantly faster for displays with high target density than for those with low target density quadrants for both color-coded and monochrome conditions. At first glance this may appear counter-intuitive, but one should note that the observers were actually being asked to detect a difference between quadrants. Hence, a high target density quadrant was more different from the other quadrants than a low target density quadrant and therefore easier to detect.

Although all response times were faster with high target density quadrants, the Airborne and Submerged categories always yielded significantly slower response times than the other four types of categories--Surface, Hostile, Unknown, and Friendly. In addition, it appears that the relative difficulty with the Airborne and Submerged categories became more pronounced when the task was more difficult, i.e., with low target density quadrants than with high target density quadrants.

Differences Between Target Categories

A final finding was that, in the monochrome condition, the Surface category yielded the fastest response times, even faster than the threat categories (see Figure 1). In addition, with color-coding, the Surface category still yielded faster response times than either the Submerged or Airborne categories. We believe this may be due to the sizes of the particular shapes employed. This unexpected

finding is worthy of further investigation.

These findings clearly show that color can be successfully applied to GEOSIT displays, and have brought up several issues requiring further investigation. First, it is worth determining the effects of color-coding on search for contacts defined two-dimensionally, such as Hostile Submerged, or Friendly Airborne, rather than on only one dimension, as in the present study. Second, what are the effects of non-redundant color-coding? With only color, and not shape, to code threat level, the reduction in display "noise" may result in faster search times. Third, are there ways of improving performance on the platform dimension, particularly for Airborne and Submerged symbols? Perhaps minor modifications can reduce the performance deficit for these symbols. Fourth, perhaps both threat level and platform type can be redundantly color-coded without unnecessary display clutter by using different lightnesses or saturations of the same three colors used in the present study to code platform type. Work is continuing on these issues.

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